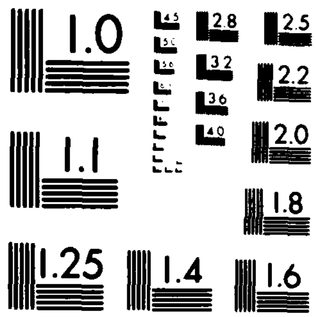
AD-A136 525 PROBLEMS IN THE DEVELOPMENT OF HIGH-POWER TURBOGENERATORS WITH SUPERCONDU..(U) FOREIGN TECHNOLOGY DIV WRIGHT-PATTERSON AFB OH G G BORZOV ET AL. 1/1

UNCLASSIFIED 05 DEC 83 FTD-ID(RS)T-1310-83 F/G 10/2 NL

END
DATE
FILMED
1 - 84
DTIC



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963-A

FTD-ID(RS)T-1310-83

FOREIGN TECHNOLOGY DIVISION

PROBLEMS IN THE DEVELOPMENT OF HIGH-POWER TURBO-GENERATORS WITH SUPERCONDUCTING FIELD WINDINGS

by

G.G. Borzov, I.A. Glebov, et al

EDITED TRANSLATION

FTD-ID(RS)T-1310-83 5 December 1983

MICROFICHE NR: FTD-83-C-001480

PROBLEMS IN THE DEVELOPMENT OF HIGH-POWER TURBO-GENERATORS WITH SUPERCONDUCTING FIELD WINDINGS

By: G.G. Borzov, I.A. Glebov, et al

English pages: 22

Source: Energetika i Transport, Nr. 4, June-August 1972, pp. 21-28

Country of origin: USSR
Translated by: Robert Allen Potts
Requester: FTD/TQTD

THIS TRANSLATION IS A RENDITION OF THE ORIGINAL FOREIGN TEXT WITHOUT ANY ANALYTICAL OR EDITORIAL COMMENT. STATEMENTS OR THEORIES ADVOCATED OR IMPLIED ARE THOSE OF THE SOURCE AND DO NOT NECESSARILY REFLECT THE POSITION OR OPINION OF THE FOREIGN TECHNOLOGY DIVISION.	PREPARED BY: TRANSLATION DIVISION FOREIGN TECHNOLOGY DIVISION WP-AFB, OHIO.

U. S. BOARD ON GEOGRAPHIC NAMES TRANSLITERATION SYSTEM

Block	Italic	Transliteration	Block	Italic	Transliteration
А а	*А а*	A, a	Р р	*Р р*	R, r
Б б	*Б б*	B, b	С с	*С с*	S, s
В в	*В в*	V, v	Т т	*Т т*	T, t
Г г	*Г г*	G, g	У у	*У у*	U, u
Д д	*Д д*	D, d	Ф ф	*Ф ф*	F, f
Е е	*Е е*	Ye, ye; E, e*	Х х	*Х х*	Kh, kh
Ж ж	*Ж ж*	Zh, zh	Ц ц	*Ц ц*	Ts, ts
З з	*З з*	Z, z	Ч ч	*Ч ч*	Ch, ch
И и	*И и*	I, i	Ш ш	*Ш ш*	Sh, sh
Й й	*Й й*	Y, y	Щ щ	*Щ щ*	Shch, shch
К к	*К к*	K, k	Ъ ъ	*Ъ ъ*	"
Л л	*Л л*	L, l	Ы ы	*Ы ы*	Y, y
М м	*М м*	M, m	Ь ь	*Ь ь*	'
Н н	*Н н*	N, n	Э э	*Э э*	E, e
О о	*О о*	O, o	Ю ю	*Ю ю*	Yu, yu
П п	*П п*	P, p	Я я	*Я я*	Ya, ya

*<u>ye</u> initially, after vowels, and after ъ, ь; <u>e</u> elsewhere.
When written as ё in Russian, transliterate as yё or ё.

RUSSIAN AND ENGLISH TRIGONOMETRIC FUNCTIONS

Russian	English	Russian	English	Russian	English
sin	sin	sh	sinh	arc sh	$\sinh^{-1}$
cos	cos	ch	cosh	arc ch	$\cosh^{-1}$
tg	tan	th	tanh	arc th	$\tanh^{-1}$
ctg	cot	cth	coth	arc cth	$\coth^{-1}$
sec	sec	sch	sech	arc sch	sech^{-1}
cosec	csc	csch	csch	arc csch	csch^{-1}

Russian	English
rot	curl
lg	log

GRAPHICS DISCLAIMER

All figures, graphics, tables, equations, etc. merged into this translation were extracted from the best quality copy available.

PROBLEMS IN THE DEVELOPMENT OF HIGH-POWER TURBOGENERATORS WITH SUPERCONDUCTING FIELD WINDINGS

G. G. Borzov, I. A. Glebov, L. P. Gnedin, V. V. Dombrovskiy, V. G. Novitskiy, V. N. Shakhtarin

(Leningrad)

The advantages of cryoturbogenerators in comparison with turbogenerators of ordinary use are stated, the structural elements of powerful cryoturbogenerators are described and the results of model tests are presented.

Scientific problems are formulated, which must be solved during the development of powerful turbogenerators. 4 illus., 6 references, p. 21-28.

Introduction. At the present time thermal energy is converted

into electric with the aid of an intermediate form of energy - mechanical. This method of energy conversion remains basic also for the decade ahead. However, the continuous growth of the powers of energy systems leads to significant increase of the powers of separate units. If the existing rates of increase of powers would be maintained, then according to estimate of Japanese specialists [1] it would be possible to expect maximum power of the unit around 6000 MW at the 1985 level and around 30000 MW at the level of the year 2000. The predictions of recent years show that such large powers are not real, and, apparently, should be directed for the year 2000 toward power on the order of 5000 MW.

The development of turbogenerators operating at power 2000-3000 MW in ordinary use is an extremely complicated problem. In connection with the large overall dimensions and weights of such machines the questions of the technology of their manufacture, the obtaining of initial materials and transportation to the places of installation become exceptionally difficult.

The application of deep cooling at the temperature level of liquid helium and the use of superconductors for the field winding of generators make it possible to increase the magnetic induction in high-power machines by several times. This gives the possibility to develop turbogenerators with significantly lower weights and

simultaneously with considerably higher efficiency. In this case is taken into account not only the generator itself, but also the refrigerator installation. Thus, the introduction of turbogenerators with superconducting field windings (cryoturbogenerators) can be caused not only by achievement of limiting powers for machines of ordinary use, but also by their higher economic factors.

Types of constructions. Cryogenic electric machines have a number of peculiarities (necessity of cooling the windings to very low temperatures, high values of magnetic field induction, possibility of elimination of ferromagnetic circuit), which can demand radical change of the construction of machines.

Synchronous machines with cryogenic cooling can be made both with fixed inductor and with rotating inductor. The creation of a stationary inductor is a comparatively simple task, since in this case the superconducting field winding can be placed in a fixed metal cryostat. The development of such a cryostat does not cause great difficulties. The armature winding can be both stationary and rotating. In the case of stationary winding a change of the magnetic field can be achieved both due to the use of ferromagnetic rotor with different magnetic conductances in longitudinal and transverse axis, and due to rotation of superconducting screens [2]. In machines of the first type the maximum induction of magnetic field in the working

zone cannot exceed the saturation induction of the ferromagnetic material of the rotor. In machines of the second type the induction of the working field can be higher, but for cooling is required the transfer of cooling agent to the rotating part. Both these constructions use a pulsating magnetic flux, which lowers the efficiency of the machine. In the case of rotating armature winding there is achieved maximum change of flow within a double amplitude value. But in this case the necessity of transfer of the total power of the machine through the rotating contact appears, which is a very difficult problem.

For the purpose of eliminating the movable contact in England was proposed a construction of synchronous generator with reciprocating movement of the armature [3]. The magnetic field in this machine is created by superconducting toroidal field winding. The phase sections of the armature are moved perpendicular to the lines of magnetic induction by a crank and connecting-rod mechanism. Current pickup is accomplished with the aid of springs or flexible connections. Calculations showed that with power 500 MW such a generator should have considerably lower weight and losses in comparison with an ordinary turbogenerator. However, realization of a machine with reciprocating motion of the armature requires the solution of many difficult problems.

It it possible to expect that the most effective structural solution will be the ordinary use of the machine - with rotating inductor and stationary armature. The development of a superconducting inductor in a rotating cryostat is a complicated technical problem, the solution of which is being accomplished at the present time in the USSR and the USA [4, 5]. Below will be examined the problems of development of cryoturbogenerators of such construction.

Possibilities of raising the power. Unit power of the turbogenerator P is determined by its dimensions and electromagnetic loads - by induction B and linear current load A on the diameter of the armature winding D_1, with active length l and speed of rotation n

$$P = 0{,}116\, k_{o6} D_1^2\, l n AB, \qquad (1)$$

where k_{o6} - winding coefficient, for the main harmonic of the field.

Rotor diameter D_2, differing from the stator diameter by the magnitude of the double air gap 2δ, including the wall thickness of cryostats, is limited by strength with runaway speed of rotation $n_y = k_y n$

$$D_2 = D_1\left(1 - \frac{2\delta}{D_1}\right) \leq \frac{60}{\pi n} \sqrt{\frac{\sigma_t}{\psi}}, \qquad (2)$$

where σ_t - maximum allowable stress in the material of rotor, and ψ - structural parameter, comprising, for example, for the shroud unit of

the rotor (approximately)

$$\psi \approx \frac{k_y^2}{2g}\left[\gamma_б\left(1+\frac{2h_б}{D_2}\right)+\gamma_{об}\frac{h_{об}(1-2h_{об}/D_2)}{h_б}\right]. \qquad (3)$$

Here $\gamma_{об}, h_{об}, \gamma_б, h_б$ - respectively the densities and thicknesses of the layer of winding and shroud cylinder. The thickness of the winding layer is determined by the flow density j_2 in the rotor

$$h_{об} = A_2/j_2 = \left({}^{3}/_{2}A_1 k_{об}\sqrt{\cos^2\varphi+(x_d+\sin\varphi)^2}\right)/(k_{об\,2}x_{ad}j_2). \qquad (4)$$

Let us consider that the relationship of the length of the rotor to its diameter in powerful turbogenerators is a constant value

$$l \approx 7D_2 = 7D_1(1-2\delta/D_1), \qquad (5)$$

that linear load is limited by maximum allowable value of transient reactance (according to conditions of stable operation in the power system)

$$A \leqslant \frac{x_d' B\cdot 10^6}{8f\delta(1-2\delta/D_1)}\sqrt{\frac{\sigma_t}{\psi}} \qquad (6)$$

and that induction is limited by the amount of maximum allowable induction in the rotor on superconductor $B_{кр}$

$$B \leqslant \frac{B_{кр}(1-2p\delta/D_1)^2}{\sqrt{\cos^2\varphi+(x_d+\sin\varphi)^2}}. \qquad (7)$$

Then we obtain the equation of power of two-pole turbogenerator without magnetic core in the rotor in the following form:

$$P_{\text{макс}} \approx \frac{710}{n^2} \cdot \frac{(j_t/\psi)^2 x_d' B_{\text{кр}}^2 (1 - 2\delta/D_1)}{[\cos^2\varphi + (x_d + \sin\varphi)^2]/\delta} \text{ MBA}^{(a)}. \quad (8)$$

Key: MVA.

Taking the maximum allowable, in the immediate future, values of critical parameters of superconductors j_2 (up to 10^9 A/m²) and (up to 10 T) and maximum allowable strengths of rotor materials (up to $8 \cdot 10^7$ kg/m²), we obtain that in the overall dimensions, achieved at present for turbogenerators with power on the order of 1 GW, it is possible to realize power on the order of several tens and even hundreds of GW.

Some structural peculiarities. During the development of the construction of cryogenic turbogenerator with rotating superconducting inductor a number of complicated technical problems appears. The main problem - the provision of strength and perfect heat insulation of the cryogenic zone.

In connection with the sharp increase of power without significant change of overall dimensions the specific mechanical loads increase. Part of them, for example loads from centrifugal forces, can be compensated for by the application of materials with raised strength and reduced density (for example, titanium, aluminum.

beryllium alloys, and also nonmetallic materials - plastics, reinforced by especially strong mineral fibers). Similarly, apparently, it is possible to solve the problem of transmission of torque to the rotor winding with minimum transmission of heat to the cold zone, selecting, as this is done in cryogenic technology, materials with large ratio of ultimate strength to thermal conductivity.

The heat insulation of the cryogenic zone of the rotor, apparently, should be high-vaccuum. The construction of the field winding itself should be distinghished by high strength because of the large forces from centrifugal and electrodynamic forces, where deformations of the winding are extremely undesirable both from the viewpoint of stability of operation of the superconductor and from the viewpoint of possible electromagnetic unbalances.

For economy of the rotor cooling system the inflow of heat through supports and losses in the superconducting winding due to variable component of the field should be reduced to minimum. The first can be achieved by different systems of dynamic heat insulation, providing intermediate dissipation of heat at different heat levels, the second - by thorough shielding of the winding by special screens made of specially pure metals. Despite these measures, the heat transfer surface of the superconducting field

winding must be sufficiently large, and the feed conditions of the cooling agent should allow some reserves in terms of heat transfer taking into account transient processes.

Of the greatest complexity are constructions of the sections of shaft, entering the cold zone: their cross section is determined by the moment of rotation and the diameter of the rotor, therefore even with manufacture of the shaft from material with small ratio of ultimate strength to thermal conductivity there is required intensive cooling of these units at intermediate temperature level or at several levels.

The bearings of the cryogenic turbogenerators, apparently, in a number of cases can be placed outside the cold zone, having provided reliable heat insulation of journals and preheating of oil. Concerning seals, their placement on the boundary of the warm and cold zones, apparently, requires nonlubricated construction.

The structural materials of the elements, surrounding the rotor, - cylinder, separating the cavity of the rotor from the surrounding space and providing the creation of a vacuum in the clearance between the stator and rotor, end shields, seals - in short all parts entering the zone of intensive radial or face magnetic field of the rotor, must be nonconducting. It is necessary to take special

measures also for providing a safe level of variable magnetic field outside the machine. For this it is possible to use the core of the stator, being simultaneously a magnetic shunt for the end field, or compensation winding, located at a sufficient distance from the axis of the machine. In the case of application of a ferromagnetic screen, if the stator winding is made of pure metal and operates at cryogenic temperature, the screen should be located outside the cryostat of the stator; concerning the compensation winding, in some cases it can be located in the cryostat of the stator winding.

One or another construction of the stator winding is determined, primarily, by economic considerations. In cryogenic generators with relatively low use a stator winding, operating at room temperature, can find application. In very powerful cryoturbogenerators the current density is unavoidably limited "from below" by values of reactance of scattering, and the making of the stator winding from pure metal, operating at cryogenic temperature with high current density, turns out to be economically advantageous. Limitations with respect to scattering reactances in connection with increase of use lead to a toothless construction of the core (if it is preserved) and the necessity of attachment of the winding with the aid of nonmetallic materials.

The cryostat for the stator winding, made from pure metal

(aluminum, beryllium or copper), also must be manufactured from nonmetallic material. In this case the cryostat of the stator winding is an additional heat shield of the rotor, which permits simplifying the heat insulation of the rotor. Depending on the operating temperature of the stator winding, which also is determined by technical and economic calculation, the cryostat can have vacuum or simpler heat insulation. The stator winding with its manufacture from pure metal should consist of sufficiently thin transposed conductors and have a developed heat transfer surface. Its scheme should as much as possible lower the level of space harmonics of the field to avoid additional losses in the winding of the superconducting inductor under normal conditions: for powerful machines, apparently, six-phase or nine-phase windings with some improvements, making it possible to provide virtually sinusoidal shape of the curve of the armature reaction field, will find application. The arrangement of the output ends and the intrawinding connections, and also questions of soldering and welding of separate conductors during their connection present special complexity during designing of such winding.

Description of experimental model. For checking the principle feasibility and efficiency of the machine with rotating cryostat a model * of vertical use was manufactured (Fig. 1).

FOOTNOTE * B. I. Fomin, N. Ye. Yermakov, A. G. Pravdin, A. A. Matveyev took part in the manufacture of the model. END FOOTNOTE

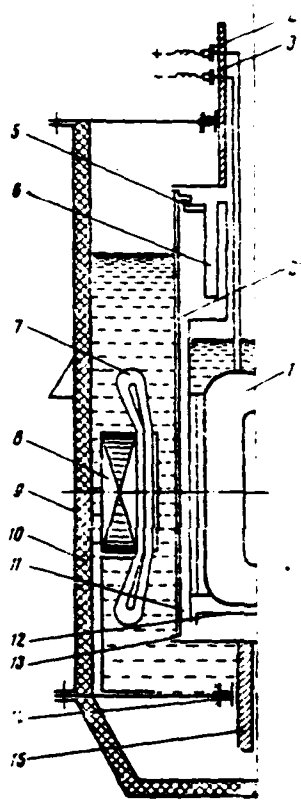


Fig. 1. Structural diagram of the model machine.

The rotor of the model is a detachable container with high-vacuum heat insulation (on the order of 10^{-5} mm Hg), made from stainless steel of brand Kh18N10T, in which is placed superconducting field winding 1. The external thick-walled cylinder 2 of the container is bolted to the ends of shaft 3. The internal cylinder -

thin-walled tubular construction with bottom 12, welded into the lower opening of the construction, through which is installed the excitation coil. The construction of the weld joint makes it possible to perform repeated removal of the bottom with the possibility of removal of the winding for its repair and subsequent replacement. The joining of the outer and inner walls is accomplished through flanges, between which is located aluminum lining 5, clamped by stainless steel bolts, providing reliable operation of the detachable vacuum seal. In the bottom part of the cryostat the sealing of vacuum gap 11 between the outer and inner cylinders is provided by copper linings 13, clamped by the same bolts.

The neck of the internal container is made in the form of corrugation for decreasing the heat inputs and is covered with a foam-plastic plug, through which passes the overflow pipe for the pouring of liquid helium, exiting outside through the internal cavity of the top end of the shaft. Here pass current inlets and measuring conductors. On the outside of bottom 12 is installed activated carbon. Pumping out of the vacuum space is done through a valve, installed in the lower end of shaft 15.

Housing 9 of the machine also is a cryostat in the form of thin-walled cylinder (thickness 10 mm) made of stainléss steel, lined inside by foam plastic 10, creating heat insulation. Between the

housing and the rotor is placed the stator, consisting of ferromagnetic core 8, playing the role of a screen, and winding 7, made from ordinary copper. The space between the housing and rotor is filled with liquid nitrogen, the level of which reaches the upper flange with seal 5. Bearing 14 with textolite separator is completely immersed in the liquid nitrogen. Supply of the field winding 1 is accomplished through a brush apparatus and contact rings 4, made of M3 copper.

A pulley is fastened on the upper end of the shaft. The drive is accomplished from direct-current motor PN-85 through a V-belt. The nominal speed of rotation of the rotor is 3000 rpm.

The field winding consists of two coils, each of which contains three coaxial rectangular sections, connected in series. The winding of the coils is made on a steel frame with twisted indium-coated cable, containing six superconducting strands made of alloy 65BT 0.25 mm in diameter and one copper strand of the same diameter. Insulation of the cable is made with Lavsan fiber. The number of turns of the field winding of the cable is 1480. The cross section of the framework of winding 30x250 mm^2, width of winding - 100 mm, active length - 250 mm, critical current - 159 A.

The stator of the machine of ordinary use, with ferromagnetic

core, plays the role of screen. The active length of the stator - 104 mm, diameter of bore - 230 mm, number of grooves - 48, number of turns per phase - 176, number of pairs of poles - 1. The winding drive consists of three copper strands, diameter of each strand 1.14 mm. The spacing of the section of winding along grooves y_1=16, active phase resistance at 20° C is 1.08 Ω, phase inductance 2.29 H.

Results of model tests. Heat tests of the model were conducted by measuring the quantity of evaporating cooling agents. The evaporability from the fixed rotor was 6.5 l/min of gaseous helium, which corresponds to heat input 0.386 W. During acceleration of rotor from zero to nominal speed the heat inputs to liquid helium were increased to 3.08 W. In steady-state mode at nominal speed of rotation the heat inputs equalled 2.94 W. Increase of the evaporability of liquid helium during rotation can be explained by the entry of liquid helium in the upper part of the internal cylinder, being close to the heat zone, and also by vibrations and increase of temperature of the housing of the cryostat.

With two-phase short circuiting the evaporability of liquid helium increased 2.2 times in comparison with idling conditions, which is explained by the appearance of additional heat inflows due to the appearance of field of reverse sequence. This circumstance indicates the necessity of shielding the helium volume for the case

of nonsymmetric conditions. The consumption of liquid nitrogen with fixed rotor was 0.215 l/min, and with nominal velocity of the rotor - 1.77 l/min.

Fig. 2 shows the idling characteristic of the machine (curve 1). The ascending and descending branches coincided. The characteristic differed from rectilinear due to saturation of the back of the magnetic circuit of the stator.

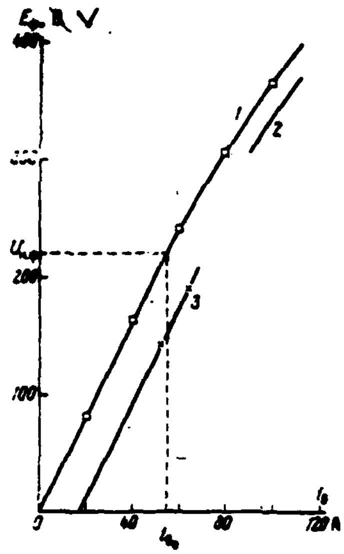


Fig. 2.

Fig. 3 shows the characteristic of three-phase short circuiting (curve 1). From idling characteristics and characteristics of symmetric short circuiting (curve 1 Fig. 3) we obtain for relationship of short circuiting value 2.47 and for synchronous

reactivity x_d =0.405.

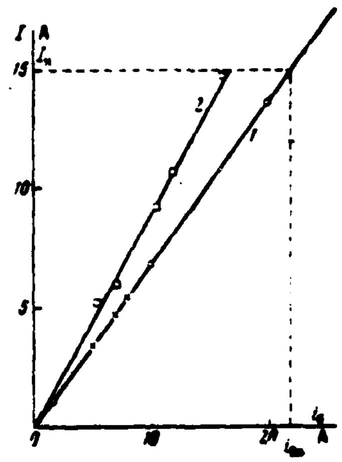


Fig. 3. Characteristics of short circuiting: 1 - three-phase, 2 - two-phase.

The load characteristics are presented in Fig. 2. Curve 2 corresponds to conditions of purely active load, curve 3 - to conditions of reactive loading (cos φ=0).

The maximum power, obtained during testing of the machine, was 18 kW, which corresponded to stator current 18 A and phase voltage 330 V with excitation current 100 A. The characteristic of two-phase short circuiting is shown in Fig. 3 (curve 2).

The value of reactance of reverse sequence, obtained from characteristics of short circuiting, x_2=0.29.

Calculation of the field of excitation under the condition of the absence of stator core was carried out according to the results of solution of three-dimensional problem of determining the induction of magnetic field of rectangular coils [6]. The results of calculation, carried out on "Minsk-22" computer, are presented in Fig. 4. The experimental values of magnetic field induction, measured by Hall type sensor Kh6TM, are shown in Fig. 4 by crosses. The experimental values are close to calculated; divergences are located within the error of experiment. The shape of the curve of the field of excitation along the pole arc is close to a sinusoid.

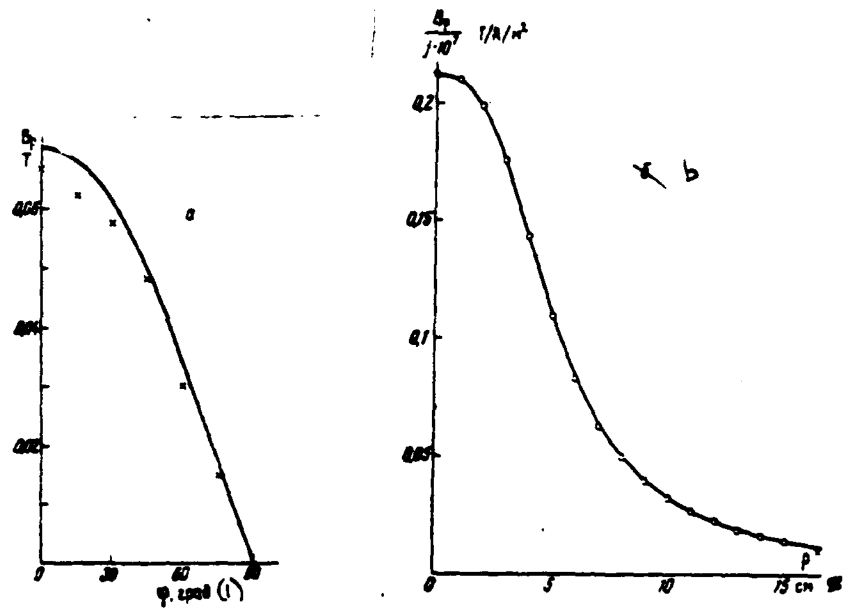


Fig. 4. Distribution of radial component of magnetic field a)

$B_\rho = f(\varphi)$ with $i_{a.s} = 50$ A, $z = 0$; b) $B_\rho / j = f(\rho)$ with z=0.

Key: (1) deg.

The presence of a stator core leads to some change of the shape of excitation field. However, the sinusoidal character of the shape of the field is preserved.

Scientific problems. The development and creation of powerful cryoturbogenerators require the accomplishment of a wide complex of scientific-research and experimental-design works. The technical and economic indices of cryoturbogenerators will depend on the successes of the creation of new structural units. The basic of them are: a) rotating cryostat with devices for feed and removal of cooling agent, providing transfer of rotating moment with small heat inputs into the low-temperature zone; b) superconducting field winding, able to perceive electrodynamic and centrifugal forces and possible vibrations, preserving the superconducting state in emergency and asymmetric conditions; c) windings made of thin conductors for the stator of grooveless construction, able to perceive electrodynamic forces in emergency conditions and having reliable water cooling or low-temperature cooling agent; d) nonmetallic cryostats for windings of alternating current in the case of their cooling to low temperatures; e) rotating seals, providing vacuuming of the gap for

lowering the losses from friction of the rotor against gas; f) screen with small losses for shielding the magnetic field in the external space of the machine and variable fields in the low-temperature zone.

The successes in the development of these and other new units of construction will depend on the achievements in the development of new types of superconducting materials, conductors of pure metals, structural materials with high strength and low thermal conductivity, nonmetallic materials for cryostats and supports with low thermal conductivity.

For cooling the windings and other units of the cryoturbogenerator there must be developed reliable, highly effective and small refrigerator installations. Apparently, progress in this region must lead to partial or complete combination of low-temperature zones of the turbogenerator and refrigerator in one construction, since in this case the total heat inputs must be sharply lowered.

For the correct calculations of conditions of cooling and heat transfer in units of construction, considerable thermophysical investigations of structural materials and cooling agents are required.

A number of new problems appears in the region of mechanics of cryoturbogenerators. Along with investigation of the mechanical properties of materials at low temperatures, methods of calculation of mechanical strength and vibration stability of structural units, methods of calculation of stresses in materials under transient heat conditions must be developed.

Special attention deserves the investigation of parameters of cryoturbogenerators and their behavior in power systems. Methods of providing stable operation of such generators, and also excitation systems, systems of automatic control, monitoring and protection must be developed. In view of the high power of cryoturbogenerators the requirements for these systems will be very high.

Conclusions. 1. The conducted analysis shows that the use of superconductors in field windings makes it possible to increase by an order the unit power of turbogenerators.

2. The results of experimental research of a model cryoturbogenerator confirmed the possibility of carrying out a synchronous machine with rotating cryostat, having low evaporability of liquid helium and providing transfer of torque.

3. For the accomplishment of powerful cryoturbogenerators it is

necessary to carry out a large volume of investigations on the development of new materials, structural units, refrigerators, automatic monitoring and control systems.

Submitted 5 Apr. 1972

REFERENCES

1. Yamamoto Mitsuyoshi. Semi — superconductive rotary machine. Conf. on Low temperature and electric power. London, 1969.
2. I. I. Pierro. L. E. Unnewehr. An Investigation of superconductivity Applied to Rotary Energy Converters. IEEE Trans. Aerospace. Rapport AS-1, 1963.
3. R. V. Harrowell. Reciprocating superconducting generator motor. Nature, 1969, v. 222, № 5193.
4. D. Thullen. J. L. Smith and oth. Economic and operational aspects of the aplication of superconductors in steam turbine generator field windings. Conference Paper, presented to of the IEEE Winter Meeting (New York, 1970, 25—30 January), No 70 CP 211-PWR.
5. Н. Н. Анемподистова. В. В. Домбровский. Возможности создания электрических криомашин большой мощности. Сб. «Теория, расчет и проектирование мощных электрических машин», «Наука», 1967.
6. В. Б. Зенкевич, Е. Я. Казовский. М. Г. Кремлев, В. В. Сычев, М. И. Федосов, В. Н. Шахтарин. Сверхпроводники в судовой технике. «Судостроение», 1971.

8